# TECHNICAL NOTE
## D-409

WIND-TUNNEL INVESTIGATION OF A SMALL-SCALE MODEL OF AN

AERIAL VEHICLE SUPPORTED BY TILTING DUCTED FANS

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SUMMARY

A wind-tunnel investigation has been made to study the static lon-
gitudinal and lateral stability characteristics of a simplified aerial
vehicle supported by ducted fans that tilt relative to the airframe.
The ducts were in a triangular arrangement with one duct in front and
two at the rear in order to minimize the influence of the downwash of
the front duct on the rear ducts. The results of the investigation
were compared with those of a similar investigation for a tandem two-
duct arrangement in which the ducts were fixed (rather than tiltable)
relative to the airframe, since the three-duct configuration had been
devised in an attempt to avoid some of the deficiencies of the tandem
fixed-duct configuration. The results of the investigation indicated
that the tilting-duct arrangement had less noseup pitching moment for
a given forward speed than the tandem fixed-duct arrangement. The model
had less angle-of-attack instability than the tandem fixed-duct arrange-
ment. The model was directionally unstable but had a positive dihedral
effect throughout the test speed range.

INTRODUCTION

In an effort to provide some basic information on the stability
and control characteristics of aircraft utilizing groups of ducted fans,
the National Aeronautics and Space Administration has undertaken a pro-
gram of free-flight and static force tests on simplified models. Ref-
erence 1 presents a discussion, based in part on some of these tests,
of stability and control problems to be anticipated with this type of
vehicle. Two rather serious problems brought out in reference 1 which
seem inherent in any simple ducted-fan configuration in forward flight
are an undesirably large forward tilt angle required for trim at the
higher speeds and a noseup pitching moment which increases rapidly with
increasing forward speed. The results of force tests of two 2-duct
configurations reported in reference 2 show that the tandem arrangement
exhibits less noseup pitching moment and requires a slightly smaller
tilt angle for a given forward speed than the side-by-side arrangement

throughout the test speed range but neither configuration was considered satisfactory in these respects. Reference 2 also brought out the fact that turning vanes placed in the slipstream cf the forward duct of the tandem arrangement reduced the trim pitching moment and tilt angle required for forward flight but the power penalty associated with such an installation might be unacceptably high.

One approach to the problem of excessive tilt angles required for high speeds suggested in reference 1, would be to depart from the concept of ducted fans fixed with respect to the airframe and to tilt the ducts for the forward flight condition. With this in mind a model was designed and constructed with three ducted fens in a triangular arrangement. One duct was at the front and two at the rear, with the ducts mounted so that they could be tilted relative to the airframe. The triangular arrangement was decided upon in order that the downwash of the forward duct would not interfere with the rear ducts. It was expected that there would be an upwash around the outside of the front duct which would increase the contribution of the rear ducts to longitudinal stability and perhaps result in a stable configuration. The results of some static force tests made to obtain quantitative data on the forces and moments associated with the forward flight operation of the three-duct configuration are presented in this paper.

## SYMBOLS

All forces and moments are referred to the stability axes.

$\alpha$        angle of attack of fuselage axis relative to horizontal, deg

$\beta$        angle of sideslip, deg

$F_{Y_\beta}$        variation of side force with angle of sideslip, lb/deg

$M_{X_\beta}$        variation of rolling moment with angle of sideslip, $\frac{\text{ft-lb}}{\text{deg}}$

$M_{Y_\alpha}$        variation of pitching moment with angle of attack, $\frac{\text{ft-lb}}{\text{deg}}$

$M_{Z_\beta}$        variation of yawing moment with angle of sideslip, $\frac{\text{ft-lb}}{\text{deg}}$

MODEL AND APPARATUS

A sketch of the model is presented in figure 1. The model was a simplified research vehicle that was not intended to represent any specific full-scale machine.

The model fans were of laminated wooden construction and had a blade angle of 18° at 0.75 of the radius. Each fan was driven by a separate induction electric motor with all three motors connected to a common variable-frequency power supply.

The ducts were of laminated wooden construction and were pivoted at the midchord point of the duct. The ducts were manually set at the desired angle and locked in position.

The model was attached to a portable-strut support system by means of an internal six-component strain-gage balance. The whole model and support assembly was then installed in the 30- by 60-foot test section of the Langley full-scale tunnel. The aerodynamic forces and moments acting on the model were indicated by the six-component strain-gage balance.

TESTS

The static longitudinal characteristics of the model were investigated through a fuselage angle-of-attack range from -10° to 20° for each duct angle. A constant model fan speed of 5,000 rpm was used throughout the investigation. The tests were carried out by setting the tunnel speed and then running through the fuselage angle-of-attack range for each duct angle. Six tunnel speeds from 0 to 19.15 knots were used at each of seven duct angles from 0° to 60°.

The static lateral characteristics of the model were investigated for angles of sideslip between 20° and -20° for duct angles between 0° to 60° at a fuselage angle of attack of 0°, with the tunnel speed adjusted to give zero drag for the particular duct angle with the fuselage at an angle of attack of 0° and angle of sideslip of 0°. No wind-tunnel corrections have been applied to the data since the model is very small in proportion to the size of the tunnel.

RESULTS AND DISCUSSION

No attempt has been made to nondimensionalize the data because of the difficulty involved in formulating a basis for coefficients which would be meaningful in both the hovering and forward-flight conditions. The use of forward speed would not have been satisfactory as a nondimensionalizing parameter because the coefficients would become infinite for the hovering condition, and the use of tip speed would not have been satisfactory because the model fans were not considered representative of the fans likely to be used in a machine of this type. For the purpose of analysis, the data have been corrected so that at the trim fuselage angle of attack of $0^\circ$ the lift equals that of a model having a fuselage width of 3 feet and weight of 75 pounds. At this weight and size, the model was considered to be directly comparable with the tandem two-duct configuration of reference 2 which represented a 1/3-scale model of a 2,000-pound machine.

Longitudinal Characteristics

The basic data from the longitudinal runs are presented in figure 2. Figure 3 shows a comparison of the variation of pitching moment with forward speed for the present tilting-duct configuration and the tandem configuration with two fixed ducts of reference 2. Since the basic data of figure 2 indicate a positive pitching moment for zero speed and zero duct angle and the basic data of reference 2 indicate a negative pitching moment for zero speed and zero angle of attack, it was necessary to apply tares to permit a direct comparison of the two sets of data. The curves of figure 3 were therefore obtained by applying to each set of data a constant pitching-moment tare that would result in zero pitching moment at zero speed and zero angle of attack or duct angle.

The data of figure 3 show that the tilting-duct configuration produces smaller pitching moments and requires somewhat smaller duct tilt angles for any given trim speed. A plot of the variation of $M_{Y_\alpha}$ with forward speed for the tandem and tilting-duct configurations is presented in figure 4. For the three-duct model, $M_{Y_\alpha}$ was measured at $0^\circ$ angle of attack at the speed at which the drag was zero at $0^\circ$ angle of attack for the various duct angles; for the tandem configuration the value of $M_{Y_\alpha}$ was measured at the angle of attack required to give zero drag at each airspeed. This plot indicates that both configurations had angle-of-attack instability at all speeds. The instability of the tilting-duct configuration, however, was markedly less than that of the tandem configuration at the higher speeds.

## Lateral Characteristics

The basic data from the lateral runs are presented in figure 5. In figure 6, the slopes of the yawing moment, rolling moment, and side force due to sideslip $\left(M_{Z_\beta}, \quad M_{X_\beta}, \text{ and } \quad F_{Y_\beta}, \text{ respectively}\right)$ are plotted against tunnel speed. The plot indicates that the model is directionally unstable at speeds above about 6 knots and the instability increases with increased speed. The data also show that the model has positive effective dihedral $\left(-M_{X_\beta}\right)$ throughout the test speed range.

## CONCLUSIONS

On the basis of static force tests of a simplified model with three ducted fans that tilt relative to the fuselage, the following conclusions are drawn:

1. The tilting-duct arrangement with the fuselage at an angle of attack of $0^\circ$ exhibits less noseup pitching moment and requires a slightly smaller tilt angle of the ducts for a given forward speed than a tandem fixed-duct configuration for any given speed.

2. The model had less angle-of-attack instability than the tandem arrangement.

3. The model is directionally unstable and has positive effective dihedral throughout the test speed range.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Field, Va., March 30, 1960.

## REFERENCES

1. McKinney, M. O.: Stability and Control of the Aerial Jeep. Preprint No. 10S, SAE Annual Meeting (Detroit, Mich.), Jan. 1959.

2. Parlett, Lysle P.: Wind-Tunnel Investigation of a Small-Scale Model of an Aerial Vehicle Supported by Ducted Fans. NASA TN D-377, 1960.
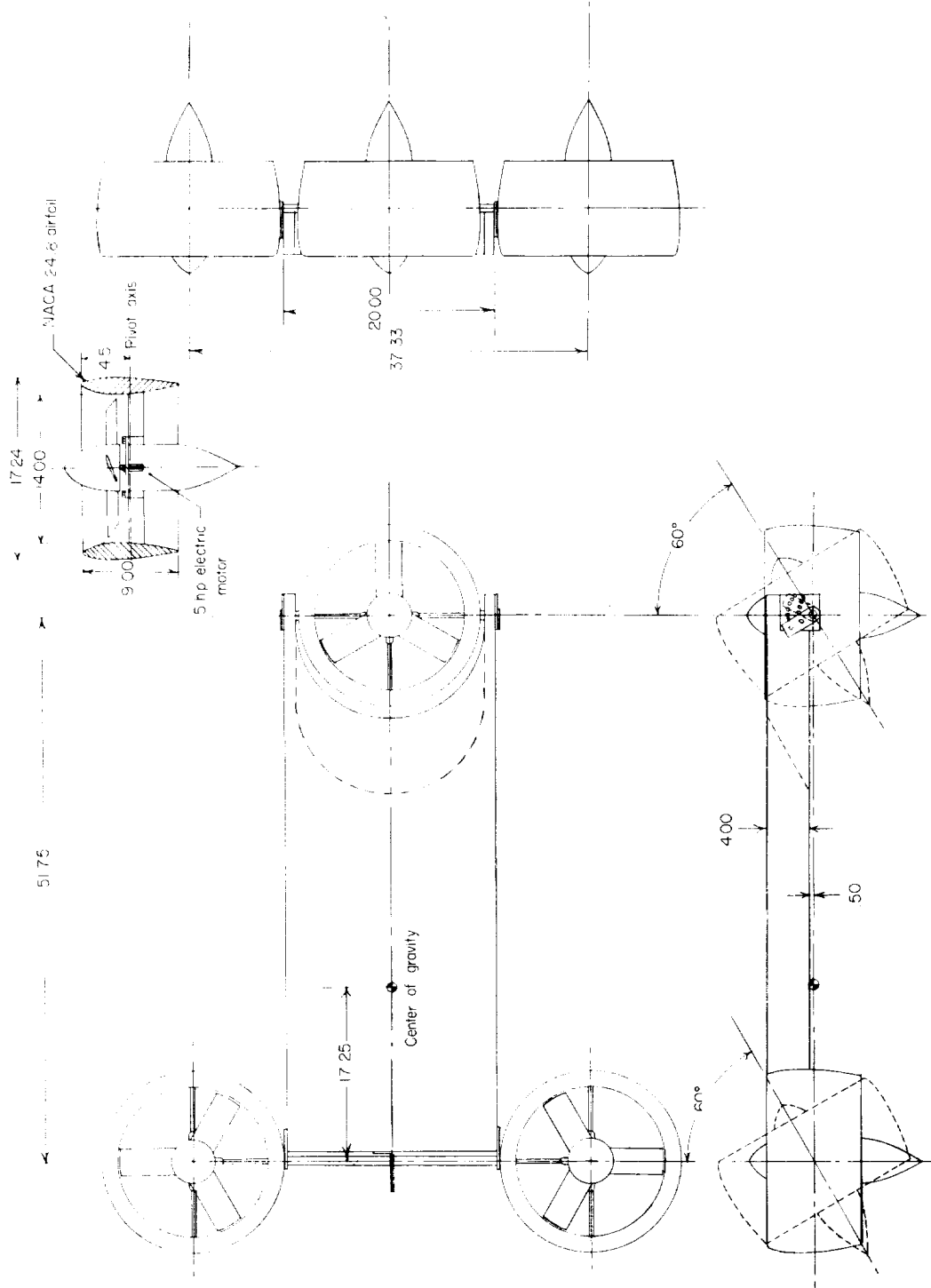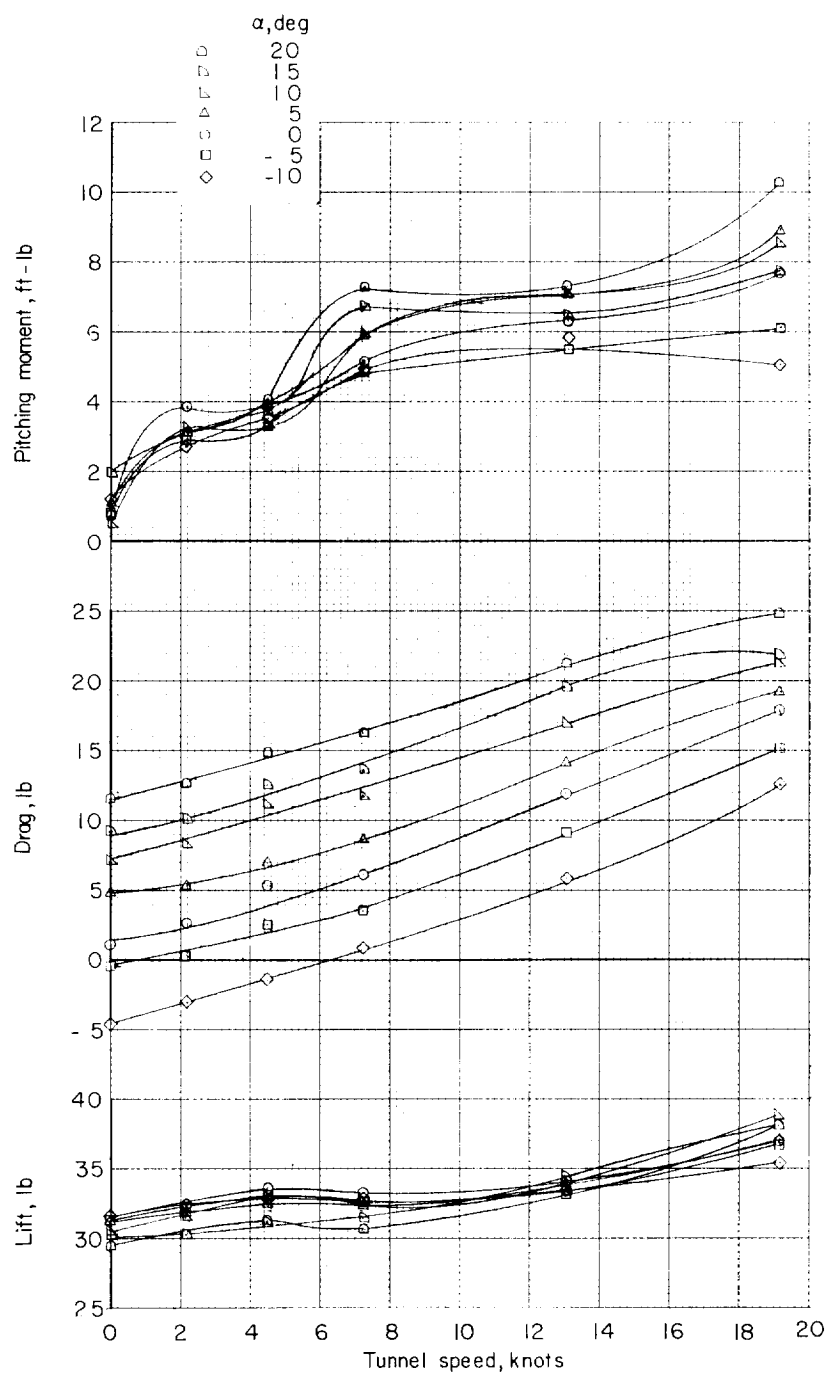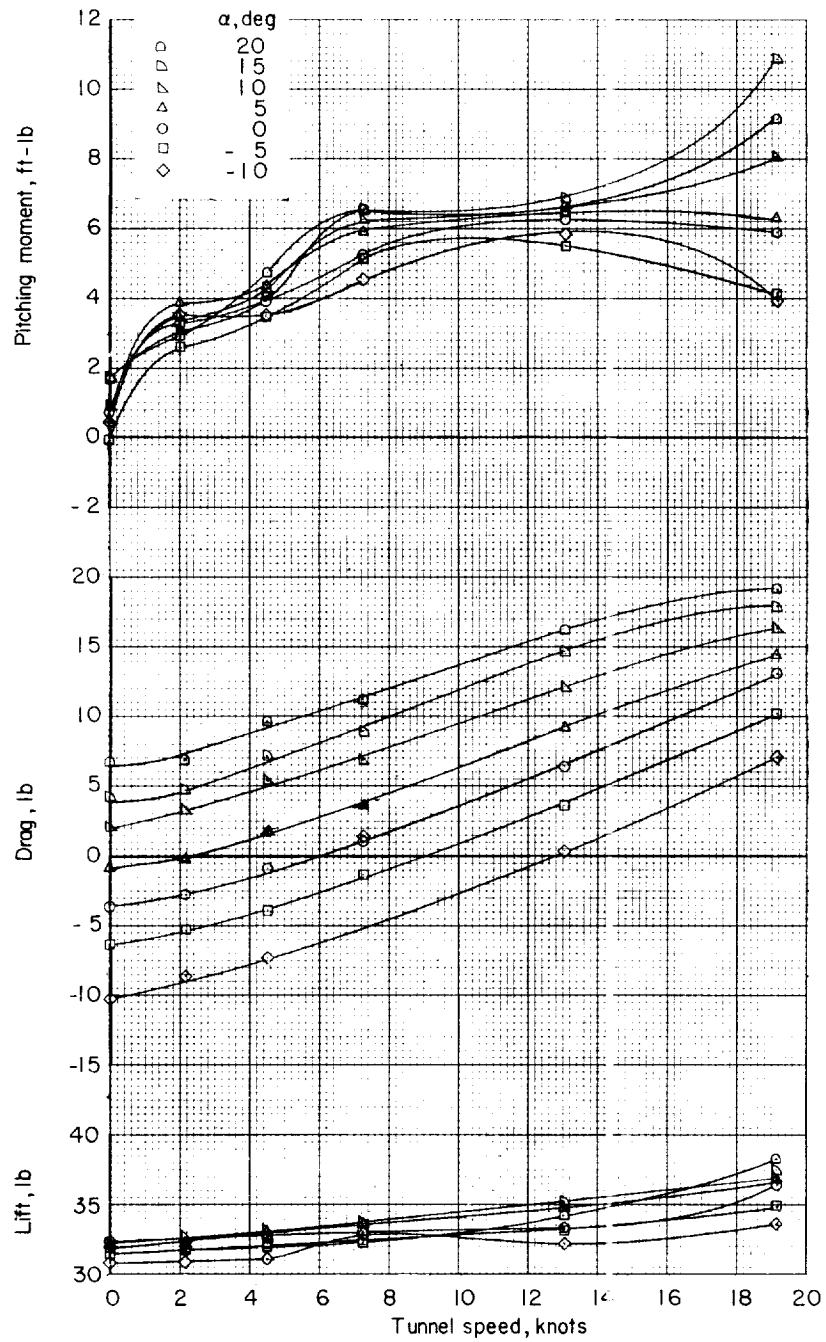
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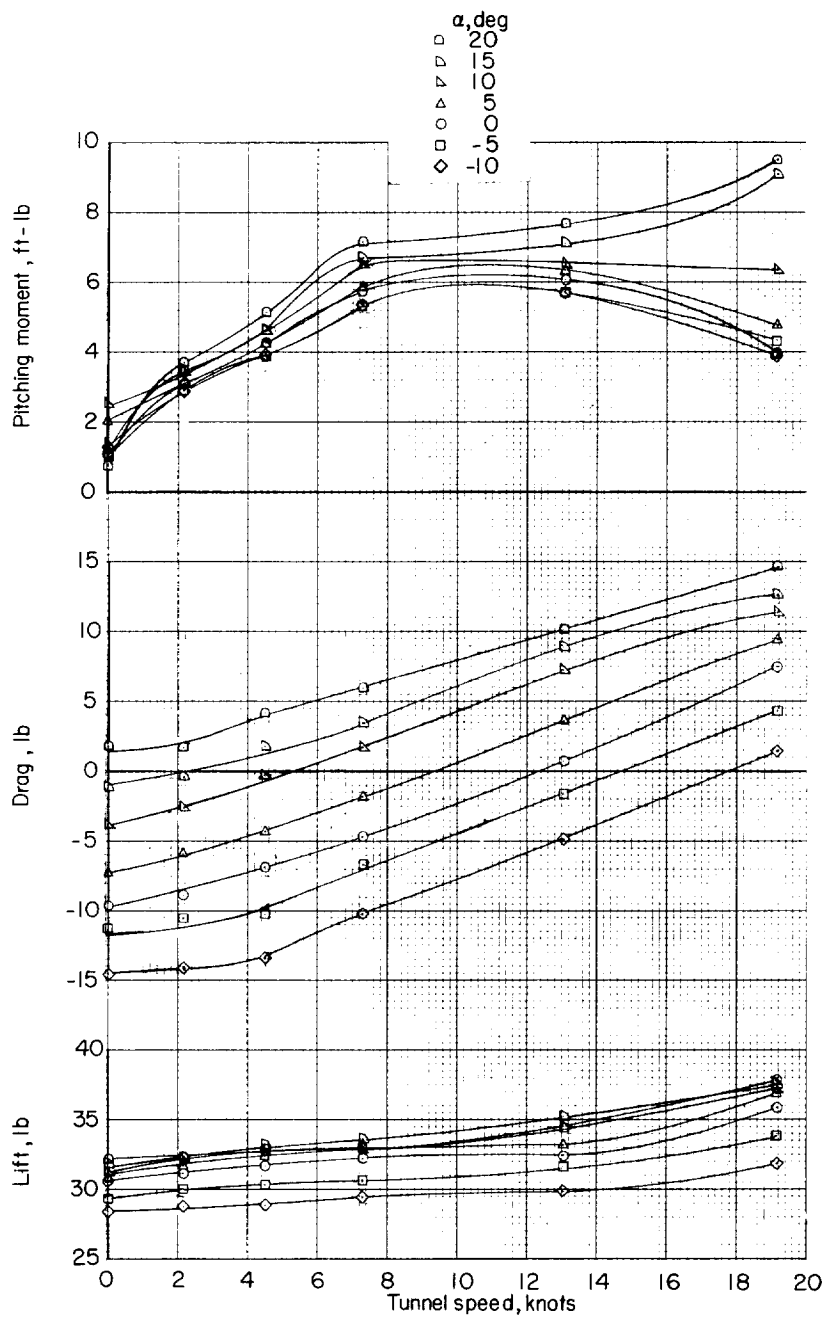


Figure 1.- Sketch of model. All dimensions are in inches.

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(a) Duct angle = 0°.

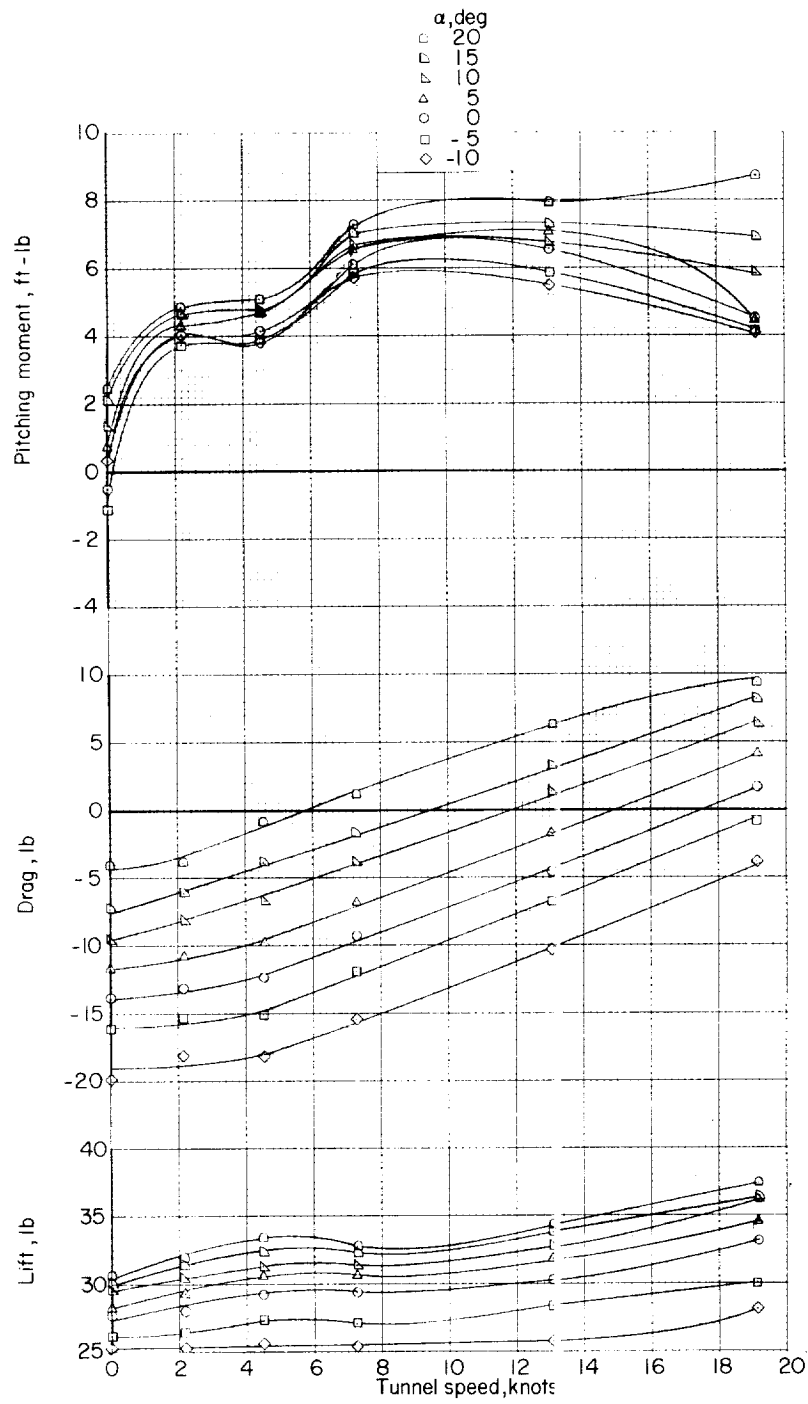Figure 2.- Basic longitudinal data.
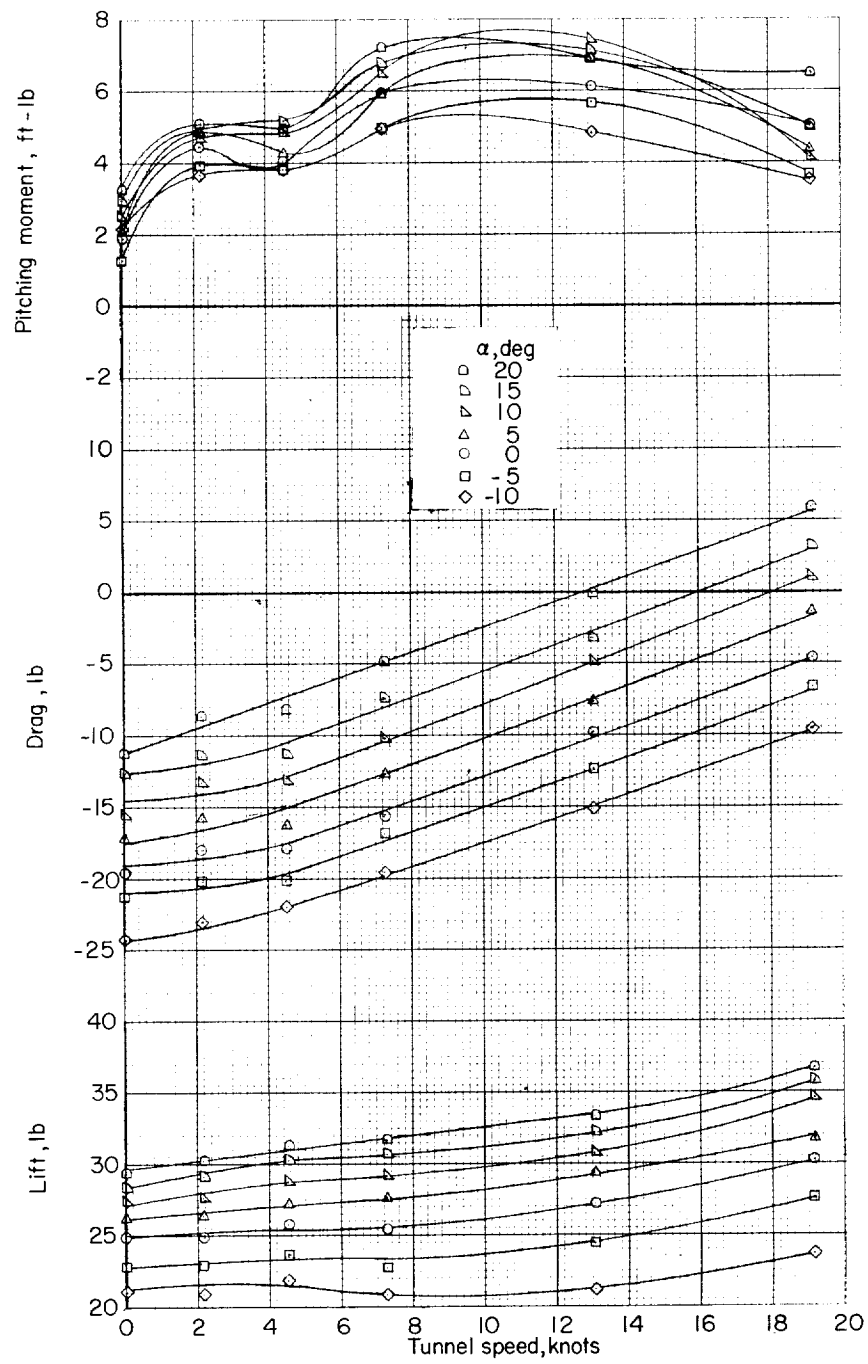
(b) Duct angle = 10°.

Figure 2.- Continued.

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(c) Duct angle = 20°.

Figure 2.- Continued.

(d) Duct angle = 30°.

Figure 2.- Continued.

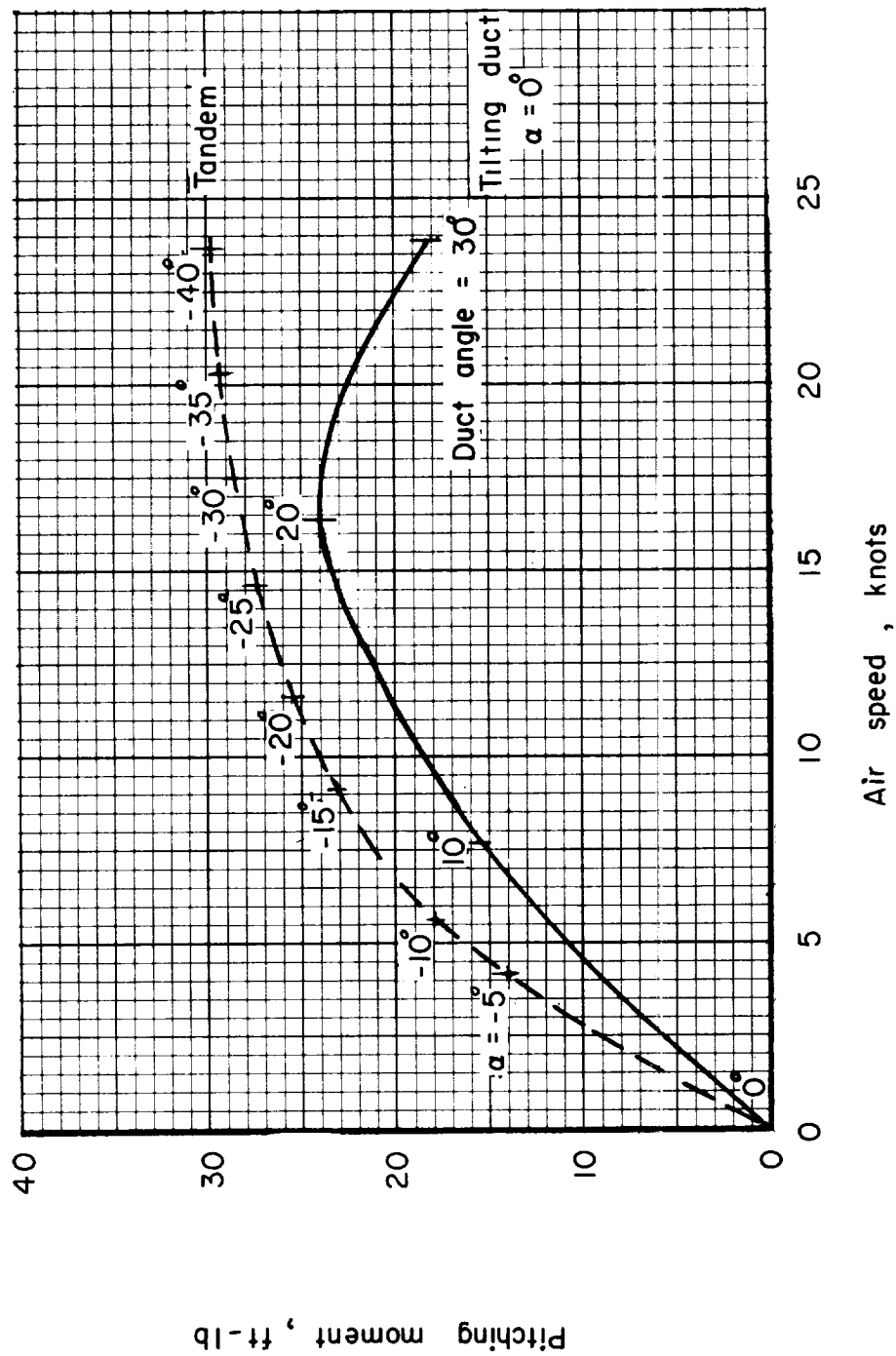(e) Duct angle = 40°.

Figure 2.- Continued.

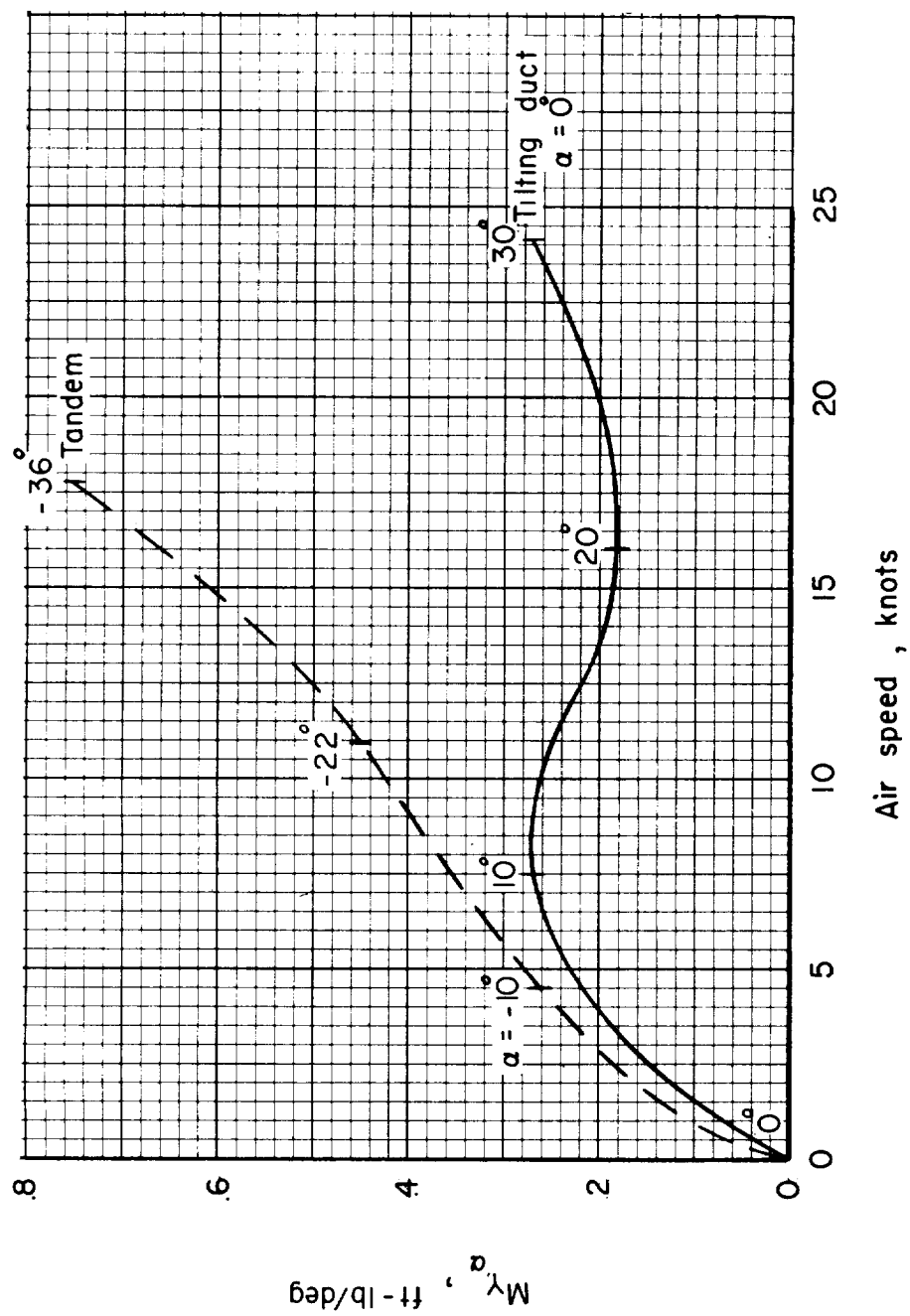Figure 3.- Variation of trim pitching moment with forward speed for the tilting-duct and tandem configurations.

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Figure 4.- Variation of $M_{Y_\alpha}$ with forward speed for the tilting-duct and tandem configurations.
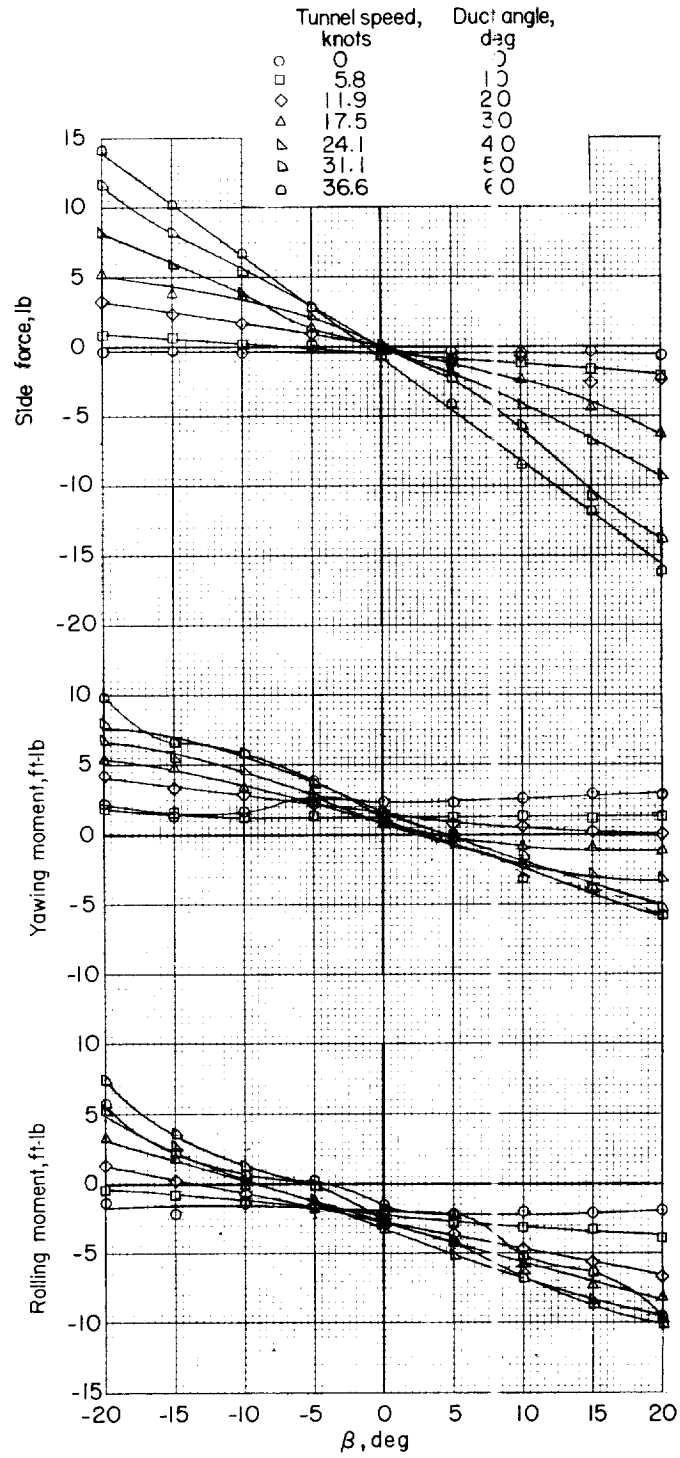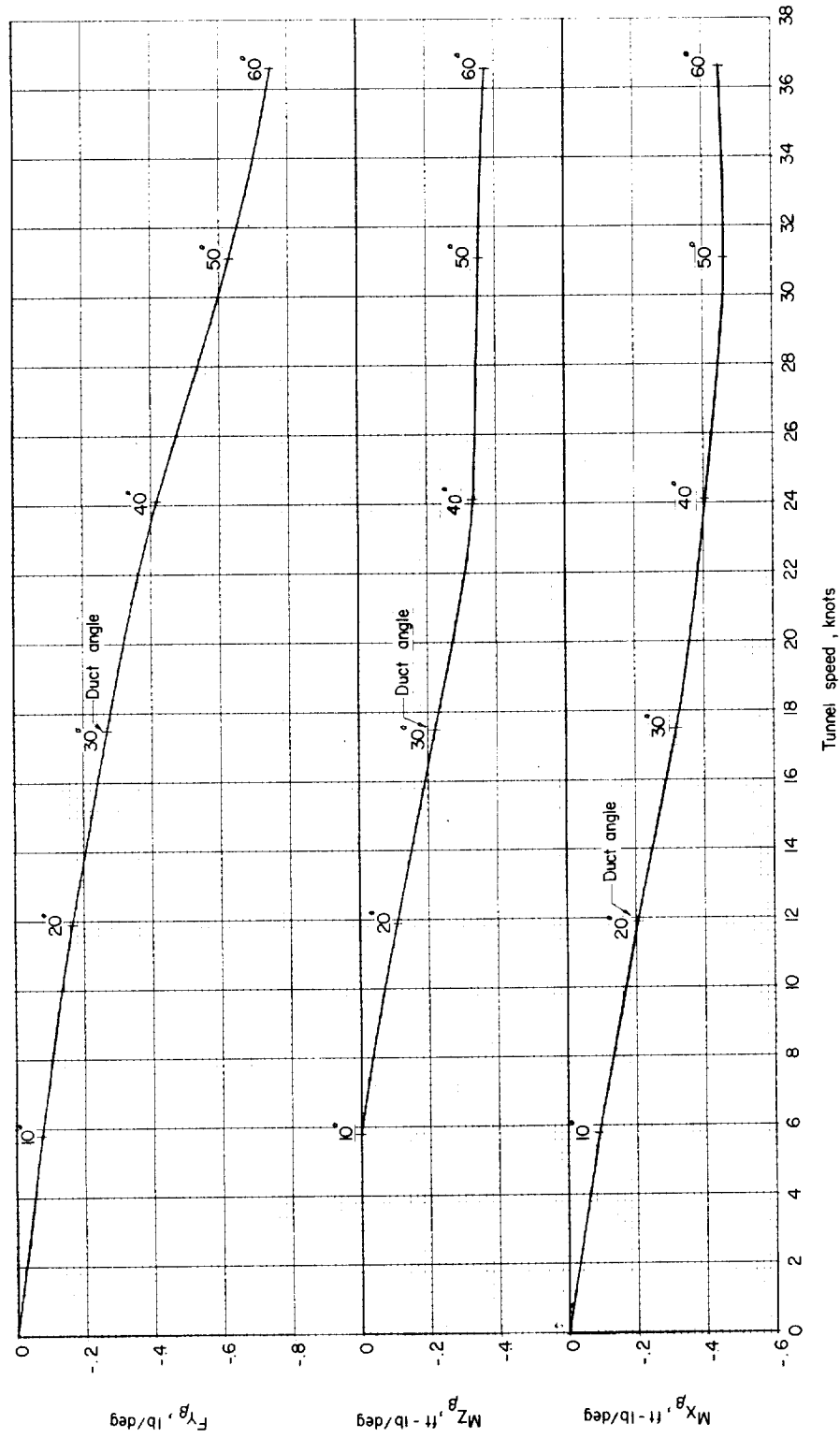
Figure 5.- Basic lateral data.

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Figure 6.- Variation of static lateral-stability derivatives due to sideslip with tunnel speed. $\beta = \pm 5°$; $\alpha = 0°$.

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